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AUTHOR McCloskey, Michael
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ABSTRACT

Two experiments were conducted to characterize the system of beliefs that make up the naive impetus theory of motion and to determine what effects physics instruction has on students' conceptions of motion. Thirteen college students were asked to solve several quantitative problems and were interviewed about their answers in the first experiment. Results indicate that these subjects held an impetus conception of motion. Three of these impetus-related misconceptions are discussed (curvilinear impetus belief, resistance to gravity, and straight-down belief). In the second experiment, high school students' (N=60) concepts of motion were examined before and after they took a physics course. Results suggest that instruction often corrects some of the gross misconceptions about how moving objects behave, but may leave others unaltered. In addition, instruction frequently fails to alter students' impetus beliefs about why moving objects behave as they do. These findings suggest the need to discuss the impetus view of motion, explaining precisely how this view differs from the Newtonian view. In addition, resistance to gravity and straight-down beliefs should be taught. Physics courses should also emphasize student understanding of the fundamentals of qualitative principles of mechanics, even if this means teaching less about the quantitative formalizations of these principles. (Author/JN)

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Naive Conceptions of Motion

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Michael McCloskey

Department of Psychology
Johns Hopkins University
Baltimore, Maryland 21218

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Several recent studies have examined high school and college students' understanding of the basic physical principles governing the behavior of moving objects (e.g., Clement, 1979, in press; Champagne, Klopfer & Anderson, 1980; Viennot, 1979; McCloskey, Caramazza & Green, 1980; Caramazza, McCloskey & Green, 1981; McCloskey, in press). The results of these studies have led a number of researchers to conclude that many students, especially those with no training in physics, have systematic, well-developed conceptions of motion that are inconsistent with the principles of Newtonian mechanics. In particular, it has been argued (Clement, in press; Viennot, 1979; McCloskey et al., 1980; McCloskey, in press) that many students hold a naive impetus theory of motion. According to the impetus theory, the act of setting an object in motion (e.g., by pushing or throwing it) imparts to the object an internal force or "impetus" that serves to maintain the motion. The theory further assumes that a moving object slows down and stops due to dissipation of its impetus. For example, according to the impetus theory a person who gives a push to a toy car to set it rolling across the floor imparts an impetus to the car, and it is that impetus that keeps the car moving after it is no longer in contact with the person's hand. However, the impetus gradually dissipates (either spontaneously or as the result of external forces such as friction and air resistance), and as a result the toy car slows and eventually stops.

The present study was aimed first at providing a detailed characterization of the system of beliefs that make up the naive impetus theory of motion. The results indicate that the general impetus conception of motion leads not only to erroneous notions about why objects behave as they do (e.g., about why the toy car stops), but also to gross misconceptions about how moving objects behave.

The experiments reported here are also aimed at determining what effects physics instruction has on students' conceptions of motion. The results sug-

gest that instruction often corrects some of the gross misconceptions about how moving objects behave, but may leave other of these misconceptions unaltered. In addition instruction may frequently fail to alter students' impetus beliefs about why moving objects behave as they do.

Experiment 1

In this experiment thirteen students at Johns Hopkins University solved several qualitative problems, and were interviewed in detail about their answers. Figure 1 shows one of the problems. For this cliff problem subjects were told that a ball positioned at the top of a cliff is given a push so that it goes over the edge of the cliff at a high speed. The subjects' task was to draw the path the ball would follow after going over the edge of the cliff, ignoring air resistance.

Four of the subjects in the experiment had never taken a physics course, three had taken high school physics and six had completed at least one year of college physics.

The results clearly indicated that most of the subjects, including those who had completed high school or college physics courses, held an impetus conception of motion. In fact, 12 of the 13 subjects gave evidence of impetus beliefs.

Several subjects stated the impetus view rather explicitly in the course of the interview. For example, one subject, who had completed a year of college physics, used the term momentum in explaining his answer to a problem involving the motion of a metal ball. When asked to explain what he meant by momentum, the subject stated that momentum was

> a combination of the velocity and the mass of an object. It's something that carries it along after a force on it has stopped....Let's call it the force of motion....It's something that keeps a body moving.

Another subject, who had taken high school physics, defined momentum as

> a force that has been exerted and put into the ball so this ball now that it's travelling has a certain amount of force....The moving object has a force of momentum and since there's no force to oppose that force it will continue on until it is opposed by something.

The impetus view can also be seen in the following explanation, given by a subject who had taken a college physics course, for the fact that a ball rolling along a flat surface will slow down and stop:

> the friction on the table or the air is exerting a force opposite to the force which is causing the motion... this [the flat surface] probably will heat up or whatever and the energy that the ball has will be less so that its speed will be less.

The assumption that a moving object has an internal force that causes it to move is quite clear in these examples.

The impetus theory was employed very frequently by subjects explaining their answers to a problem in which they drew the path followed by a projectile shot from a cannon in the absence of air resistance. For example,

> as it [the cannonball] comes up the force from the cannon is dissipating and the force of gravity is taking over....At the midpoint [i.e., the peak] the force of the cannon and the force of gravity are fairly equal. That's the changeover point, at which point the force of the cannon is less as gravity becomes the more predominant force.

Some subjects who gave this sort of explanation argued that the cannonball accelerates on the way down because of the continuing dissipation of the original upward force. This impetus explanation for projectile motion, which has also been noted by Clement (in press), is very similar to the view associated with Hipparchus, an astronomer of the second century B.C. (Clagett, 1959), and also employed by Galileo in <u>De Motu</u>.

The impetus conception of motion was manifested not only in subjects'

explanations for why objects behave as they do, but also in their ideas about how objects behave. Several impetus-related misconceptions of this sort were observed, three of which will be discussed here.

The curvilinear impetus belief. Consider the spiral tube problem shown in Figure 2A. For this problem subjects were told that

> The diagram shows a thin curved metal tube. In the diagram you are looking down on the tube. In other words, the tube is lying flat. A metal ball is put into the end of the tube indicated by the arrow and is shot out of the other end of the tube at high speed.

They were asked to draw the path the ball would follow after it emerged from the tube, ignoring air resistance and any spin on the ball. The correct answer is shown in Figure 2B.

Several of the subjects indicated that the ball, after emerging from the tube, would follow a curved path that gradually straightened (see Figure 2C). The subjects' explanations revealed that the answer reflected a belief that an object constrained to move in a curved path (e.g., by being shot through a curved tube) acquires a curvilinear impetus that causes it to continue in curvilinear motion for some time after it is no longer constrained. However, this impetus gradually dissipates, and as a result the object's path gradually straightens. For example, one subject who drew a curved path for the spiral tube problem explained that

> the momentum from the curve [of the tube] gives it [the ball] the arc...The force that the ball picks up...from the curve eventually dissipates and it will follow a normal straight line.

The curvilinear impetus belief was also manifested by subjects on several other types of problems. Table 1 gives the percentage of subjects who evidenced this belief.

Resistance to gravity. A second misconception revealed by the present experiment was the belief that gravity will not affect the path of a projectile

until the projectile's impetus decreases to some critical level. This belief also turned up on several different types of problems. For example, for the cliff problem (see Figure 1) several subjects stated that the ball, after leaving the cliff, would continue to move horizontally for some time before beginning to fall. (Figure 3). In explaining their answers these subjects indicated that the ball is initially immune to the effects of gravity. For instance, one subject stated that

> when it leaves the cliff the inertia force - the horizontal force - is greater than the downward motion force. When the horizontal force becomes less the ball would start falling.

Some subjects who held the resistance to gravity belief thought that gravity would affect an object's path when the object's impetus became weaker than the force of gravity. For example, one subject stated in the context of the cliff problem that

> eventually it [the ball] loses the momentum and gravity will take over. Gravity will become greater than the force of the [push], therefore it will begin to fall.

However, one subject believed that gravity would not affect an object's path until the object's original impetus had been entirely expended. This subject's response to the cliff problem is shown in Figure 4.

Table 1 gives the percentage of subjects who held the resistance to gravity belief.

The straight down belief. A third impetus-related misconception was revealed by the airplane problem shown in Figure 5A. In this problem subjects were asked to draw the path followed by a metal ball dropped from a moving airplane, ignoring air resistance. The correct answer is shown in Figure 5B.

A common incorrect response to this problem was that the ball would fall straight down when dropped (see Figure 5C). This erroneous response reflects a belief that objects acquire impetus when they are pushed or pulled,

but not when they are merely carried. In other words, because the ball is being carried by the airplane, it has, according to this view, no impetus to cause it to move horizontally when released. Consequently, the ball falls straight down. One subject, for example, indicated that the ball in the airplane problem would fall straight down because the carrying of the ball by the airplane

> would give the ball no force in the X [horizontal] direction...the only force acting on the ball would be in the Y direction, which is downward.

The belief that pushed but not carried objects acquire impetus can be seen very clearly by comparing responses to the cliff and conveyor problems. For the cliff problem subjects were told that a ball was given a push that caused it to move along the top of the cliff at high speed and eventually to go over the edge. For the conveyor problem, which was presented to subjects at the same time as the cliff problem, it was explained that the ball was attached to the end of a metal rod by an electromagnet (see Figure 6). Subjects were told that the rod was carried along by a conveyor belt moving at the same speed as the ball that was pushed in the cliff problem. When the ball reaches the edge of the cliff, the electromagnet is turned off, releasing the ball. For both problems subjects drew the path of the ball as it fell. A number of subjects indicated that while the pushed ball would fall in some sort of arc (Figure 7A), the curved ball would fall straight down (Figure 7B).

Naive Conceptions and Physics Instruction

Strong conclusions about the effects of physics instruction cannot be drawn from the results of Experiment 1, both because of the small number of subjects and because subjects with different amounts of physics training may have differed in their conceptions of motion even prior to instruction. However, a few general observations can be made.

Impetus-related misconceptions about how objects behave were less frequent among subjects who had completed physics courses than among those who had never taken physics. For example, 75% of the subjects with no physics hold the curvilinear impetus belief, whereas none of the High School Physics training subjects and 17% of the college physics subjects held this belief.

However, it is clear that physics instruction did not lead the subjects to abandon the basic impetus conception of motion. For eight of the nine subjects who had completed physics courses, the impetus theory was clearly evident in the subjects' explanations for why objects behave as they do. For example, several High School and College Physics subjects indicated that a projectile moves upward until its original impetus has dissipated to the point where it is no longer stronger than the force of gravity.

These results suggest that physics courses may be rather effective in altering students' ideas about how objects in motion behave, but not in changing their impetus beliefs about why moving objects act as they do. One aim of Experiment 2 was to test this hypothesis.

Experiment 2

This experiment examined high school students' conceptions of motion before and after they had taken a physics course. The subjects were 60 students from six private high schools with selective admission. Fifteen subjects were randomly assigned to each of the following four conditions: 1) Before-After; 2) After; 3) Before-Much After; 4) Much After. The labels refer to when the subjects were to be tested, with "before" meaning before taking a one-semester unit on mechanics, "after" meaning within one month after completion of this unit and "much-after" meaning seven to eight months after completion of the mechanics unit.

At this time only the Before testing and the After testing have been completed.

As in Experiment 1 subjects were given a series of problems (e.g., the spiral tube problem) and were interviewed about their answers.

A few subjects were lost for various reasons (e.g., one decided not to take physics). The data reported are from 28 subjects for the Before testing and 25 subjects for the After testing. No major differences were observed between the Before-After and Before-Much After groups on the Before testing, or between the Before-After and After groups on the After results. Thus, the Before and After results are reported collapsed across groups.

Because the After testing has just been completed, the findings reported here are preliminary in nature.

Results for the Before testing were consistent with those obtained for the No Physics subjects in Experiment 1. 26 of the 28 subjects, or 93%, clearly evidenced impetus beliefs about why objects behave as they do. As in Experiment 1 these beliefs were manifested across many different types of problem situations. For example, many of the subjects explained that a projectile shot from a cannon or a ball rolling up a hill moves upward until its initial "force" equals that of gravity, and moves down thereafter. One particularly interesting manifestation of the impetus view was observed for a problem in which a ball positioned at the top of a frictionless hill is given a push. A few subjects indicated that the ball might decelerate initially and then accelerate. These subjects explained that although gravity will tend to speed the ball up, the force from the original push dissipates, so that the net result may be an initial deceleration of the ball.

The impetus-related beliefs about how objects behave that were observed in Experiment 1 were also seen in the Before testing of Experiment 2. The first row of Table 2 presents the percentage of subjects who evidenced the

curvilinear impetus belief, the resistance to gravity belief and the straight down belief.

The results for the After testing were quite interesting. A few students showed an excellent grasp of the Newtonian conception of motion, and evidenced no trace of impetus beliefs. However, most students (specifically, 80%) clearly retained the general impetus conception of why objects behave as they do. For example, as in the Before testing many subjects gave the explanation that projectiles move upward until their upward force equals the force of gravity. Thus, the physics instruction was not terribly effective in inducing students to relinquish the impetus view.

Results for the impetus-related beliefs about how objects behave were mixed. As can be seen from Table 2, the incidence of the curvilinear impetus belief was much lower after instruction than before. However, instuction apparently had less of an effect on the resistance to gravity or straight-down beliefs.

The students' beliefs about the dissipation of impetus were clearly influenced by instruction. On the Before testing 82% of the subjects indicated that a ball that goes over the edge of the cliff will gradually lose its initial force, so that it eventually falls perpendicular to the ground (see Figure 8). However in the After testing only 44% of the subjects expressed this view. Similarly, in the Before testing 60% of the subjects indicated that a toy car given a push would slow down and stop even when friction and air resistance were ignored, but only 28% of the subjects gave this response in the After testing. Unfortunately, these results do not imply that a majority of the subjects relinquished the impetus theory for the Newtonian view. Rather, the results for the most part reflect a shift from a less sophisticated to a more sophisticated version of the impetus theory (i.e., from the view that

impetus dissipates spontaneously to the view that impetus is decreased only by external influences like friction).

Other effects of instruction were also observed. For example, subjects were much more likely to understand the decomposition of projectile motion into horizontal and vertical velocity components after taking the physics course. Nevertheless, when one considers a) that the problems used in the study concerned the most fundamental qualitative principles in mechanics, b) that the After testing took place very shortly after subjects completed the study of mechanics and c) that the students were all well above average in intelligence, the results present a rather discouraging picture of the effectiveness of high-school physics instruction.

Concluding Remarks

The results of the present experiments provide a detailed characterization of the ways in which the basic impetus conception of motion may manifest itself in specific ideas about how objects behave (e.g., the curvilinear impetus belief) and why objects behave as they do (e.g., a cannonball starts to fall when its impetus no longer exceeds the force of gravity). The results also provide information about which impetus ideas are altered by instruction and which are not.

The findings have straightforward implications for physics instruction. First, as several researchers have argued, (e.g., McCloskey et al., 1980; Minstrell, Note 1; Champagne et al., 1980), there is a clear need to discuss with students the impetus view of motion, explaining precisely how this view differs from the Newtonian conception and why the latter view is to be preferred. Second, the resistance to gravity and straight down beliefs should be explicitly addressed in instruction, as the present results suggest that the instruction received by our subjects was largely ineffective in altering

these views. On a more general level, physics courses should probably place more emphasis on ensuring that students acquire an understanding of the fundamental qualitative principles of mechanics, even if this means teaching less about the quantitative formalizations of these principles.

Reference Notes

1. Minstrell, J. Explaining the "at rest" condition of an object. Unpublished manuscript, 1980.

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Table 1

Percentage of Subjects Evidencing the General Impetus Conception of Motion and Three Impetus-Related Beliefs

General Impetus Conception	Impetus-Related Beliefs		
	Curvilinear Impetus Belief	Resistance to Gravity Belief	Straight Down Belief
92%	31%	38%	23%

Table 2

Percentage of Subjects Evidencing the General Impetus Conception of Motion and Three Impetus-Related Beliefs in the Before Testing and the After Testing*

Test Session	General Impetus Conception	Impetus-Related Beliefs		
		Curvilinear Impetus Belief	Resistance to Gravity Belief	Straight Down Belief
Before	93%	42%	53%	25%
After	80%	8%	52%	20%

*These figures are based upon a preliminary analysis of the data.

Figure Captions

1. The cliff problem

2. The spiral tube problem (A), the correct answer (B), and a common incorrect answer (C).

3. Cliff problem answer reflecting the resistance to gravity belief.

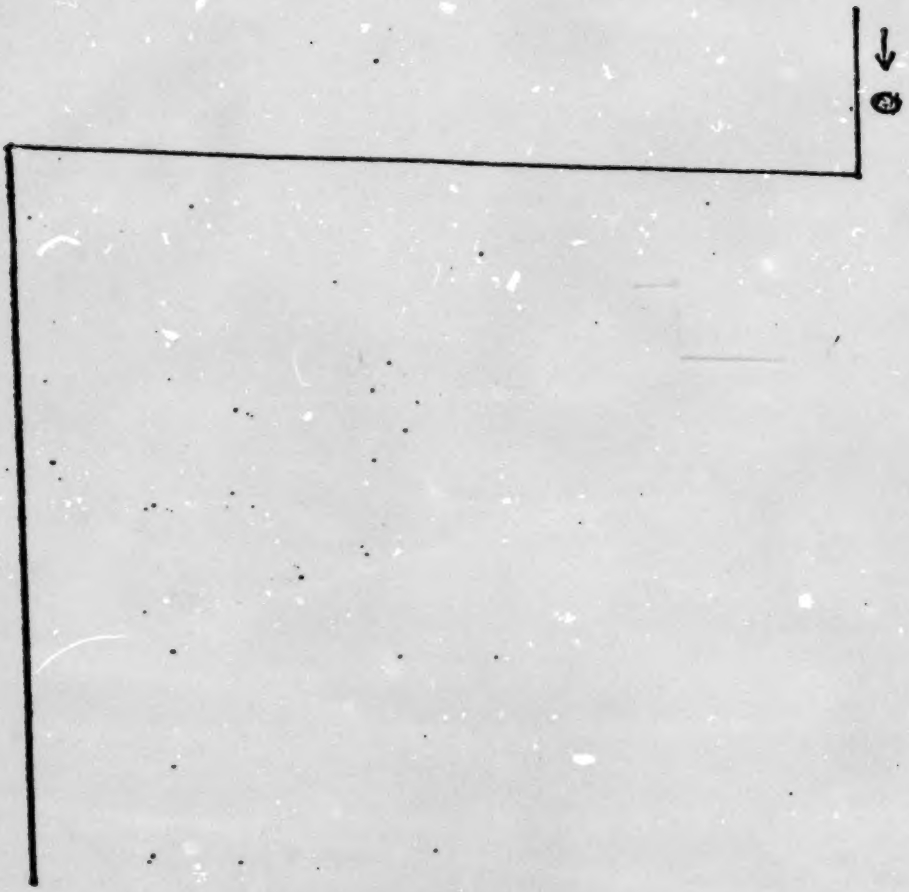
4. Cliff problem answer reflecting the belief that gravity will not affect a projectile until its original impetus has been entirely expended.

5. The airplane problem (A), the correct answer (B) and a common incorrect answer (C).

6. The conveyor problem.

7. Answers to the cliff and conveyor problems reflecting the straight-down belief.

8. Cliff problem answer reflecting the belief that impetus dissipates spontaneously.



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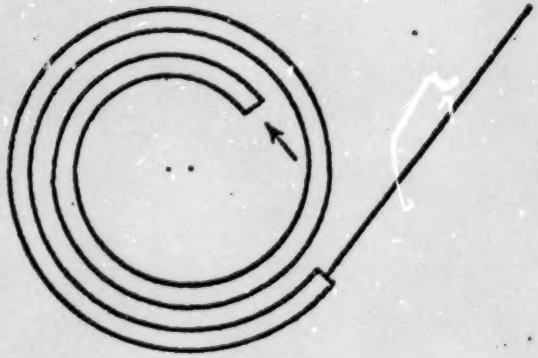
A



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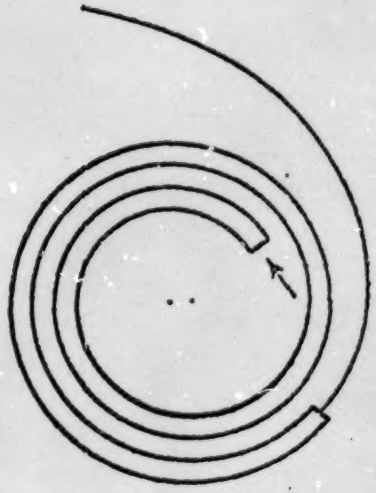

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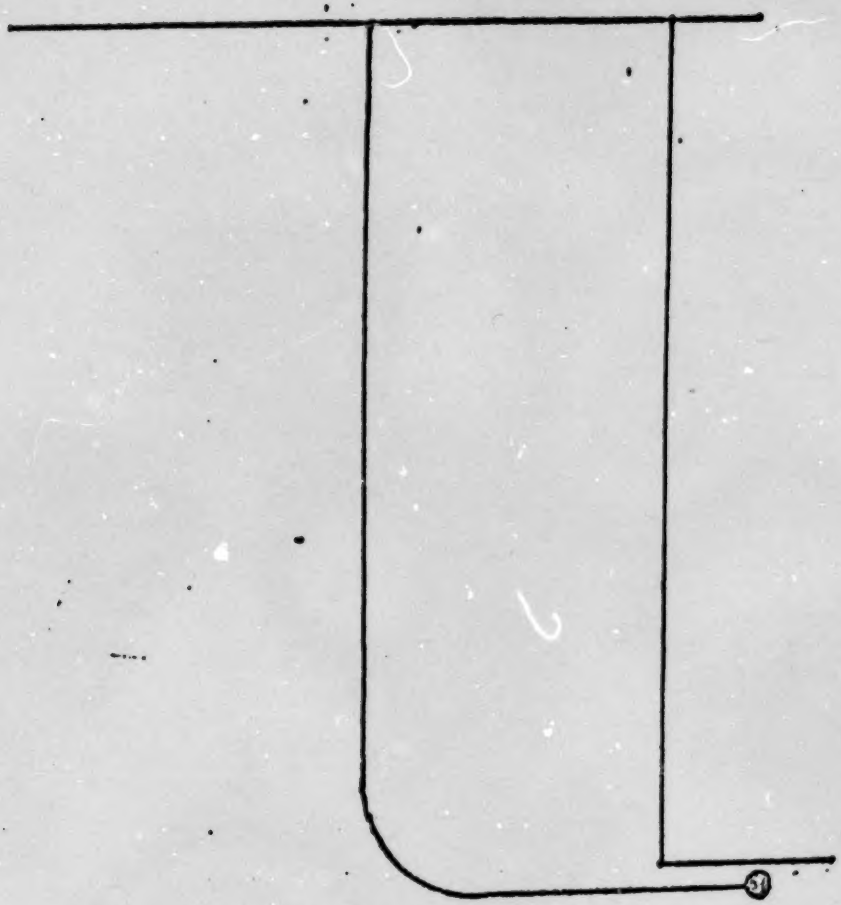

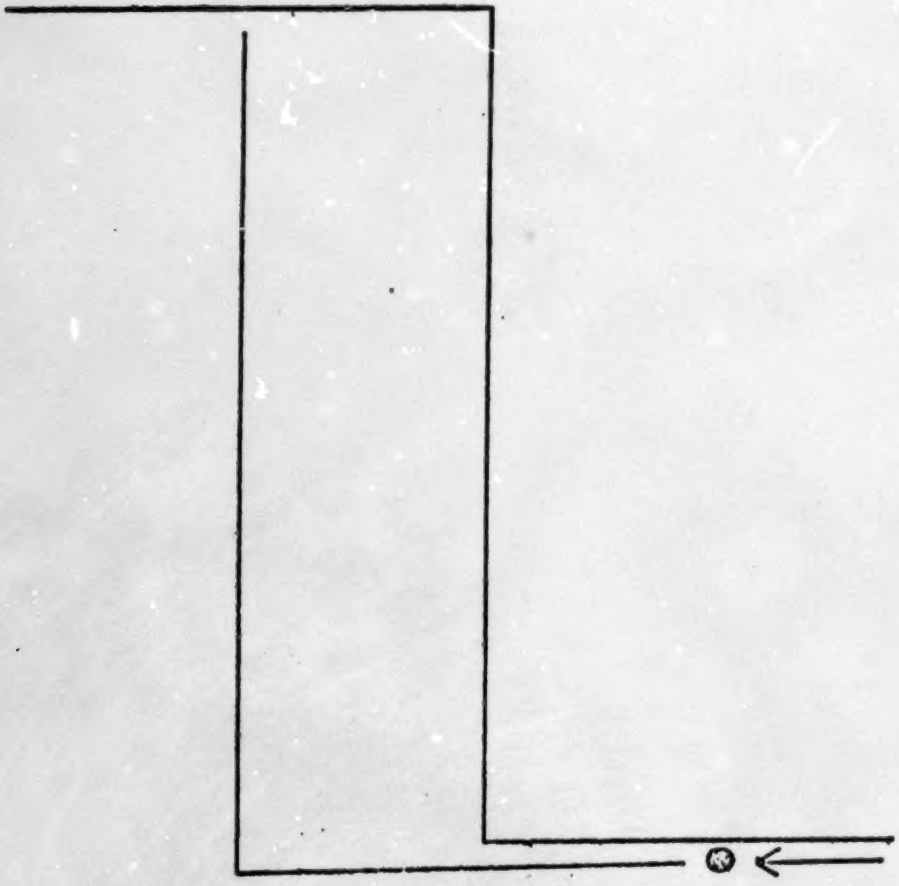

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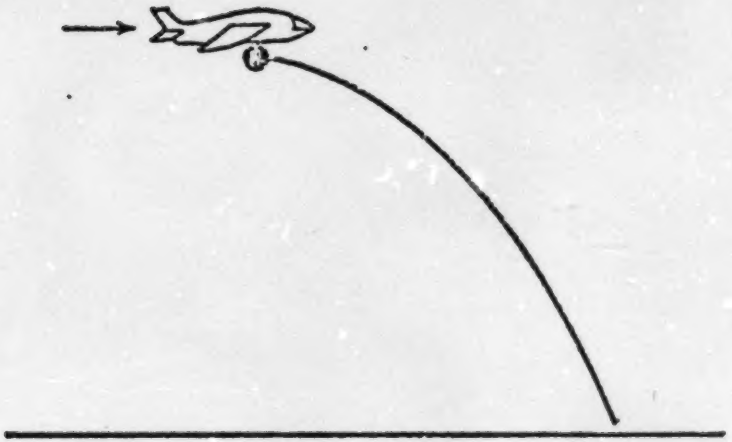

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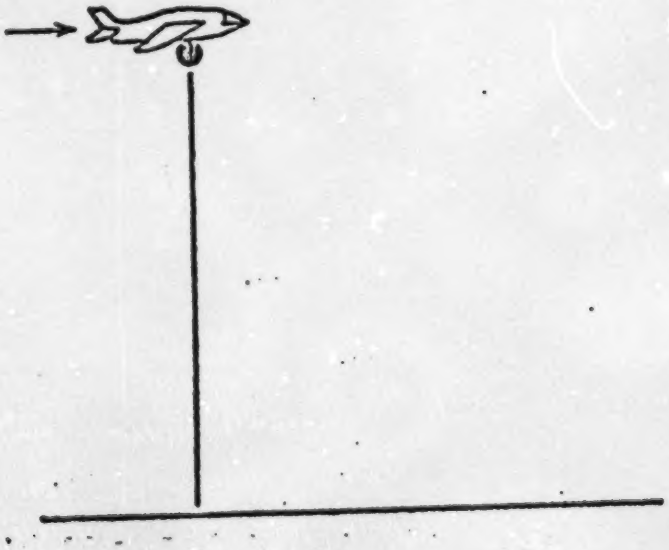

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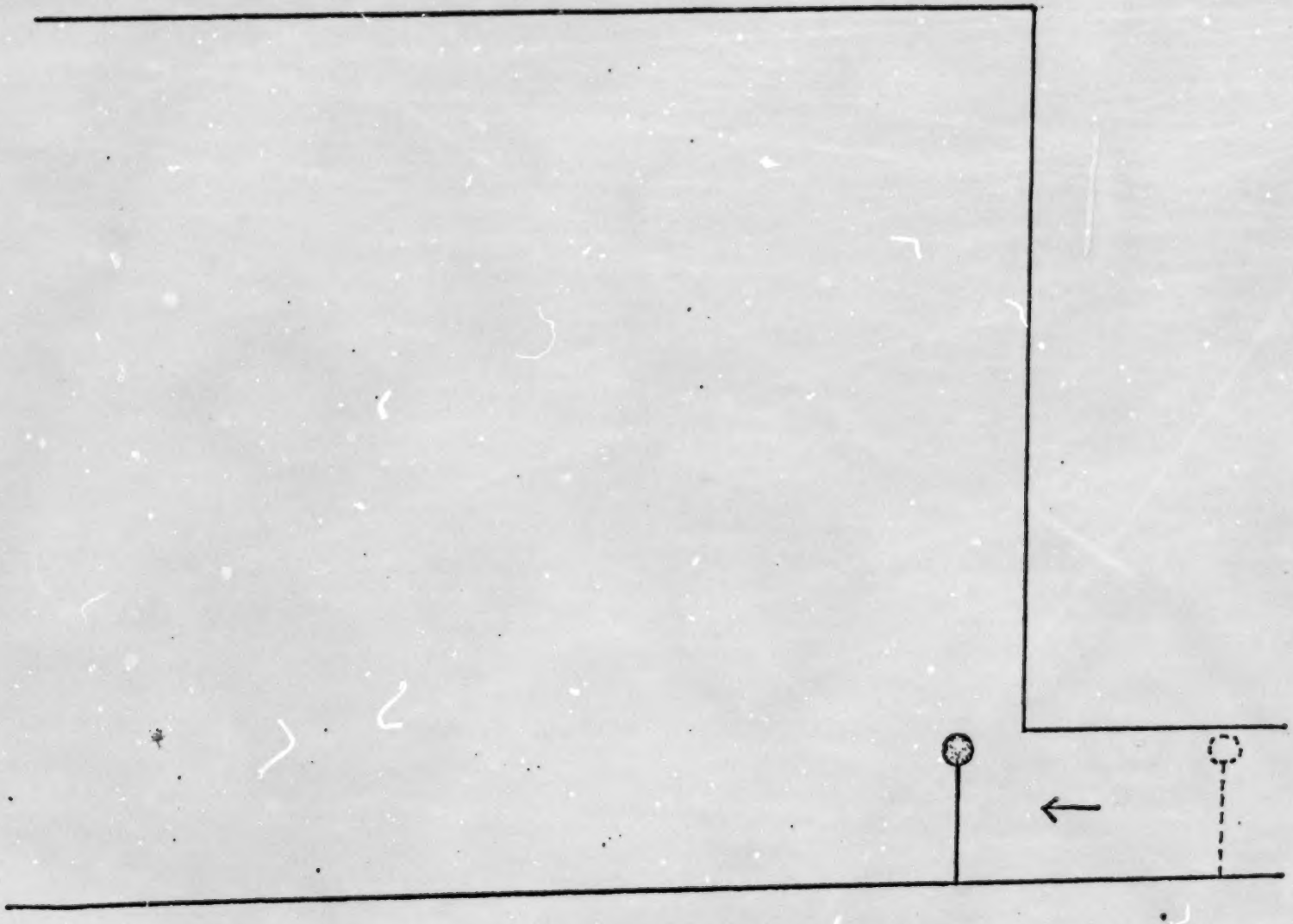

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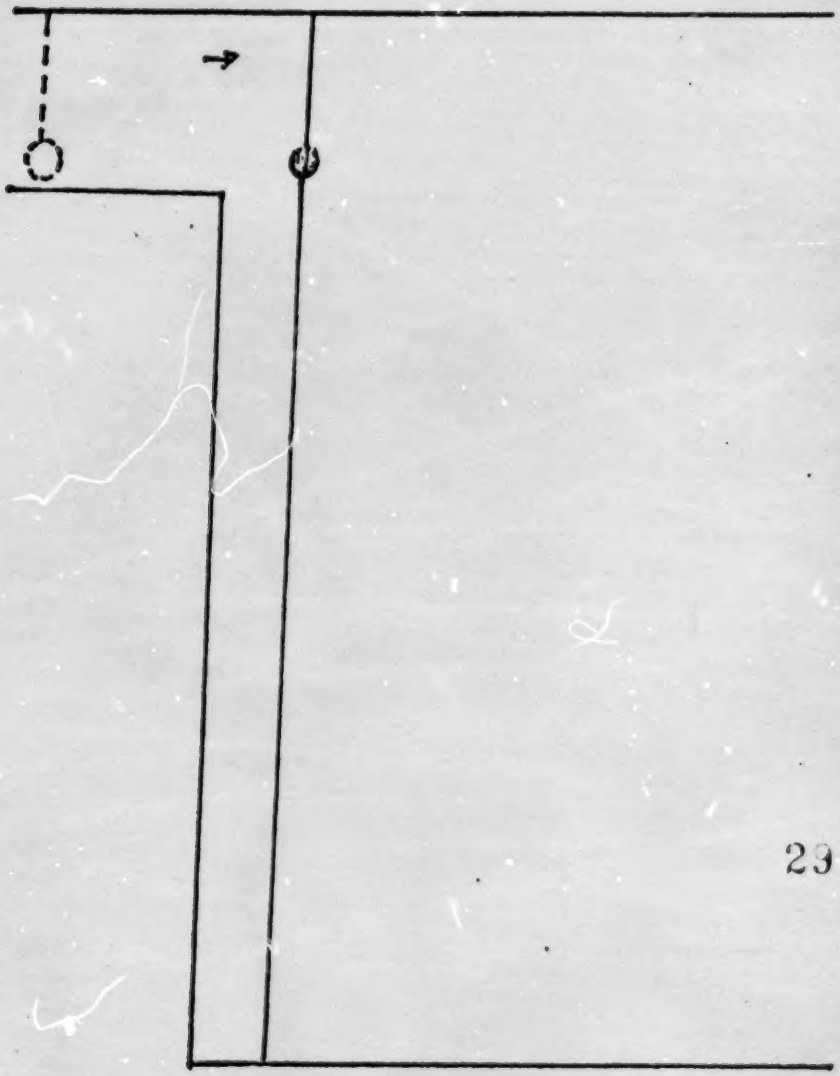

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